RECENT IMPROVEMENTS IN IERS RAPID SERVICE/PREDICTION CENTER PRODUCTS

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ABSTRACT. The International Earth Rotation and Reference System Service (IERS) Rapid Service/Prediction Center (RS/PC) at USNO has made several improvements to its combination and prediction products. These improvements are due to the inclusion of new input data sources as well as modifications to the combination and prediction algorithms. These changes and their impact on the users of the RS/PC data are presented.

1. INTRODUCTION

A review of the data provided for and users of IERS RS/PC combination and prediction solutions is presented. Recent improvements to the combination process, including using electronic Very Long Baseline Interferometry (e-VLBI) for faster data transfer of intensives, replacing extrapolated International GNSS Service (IGS) Rapid with IGS Ultra determined polar motion data, and adding one and removing two Satellite Laser Ranging (SLR) data series, is discussed. Recent improvements to the prediction process, which includes using e-VLBI, a least-squares, autoregressive algorithm (LS-AR) for polar motion determination, and an extended atmospheric angular momentum (AAM) forecast data is also discussed. Finally, an overview of the IERS RS/PC AAM process for determining Length-of-Day (LOD) is given.

2. OVERVIEW OF EOP RS/PC SOLUTION

The daily Earth Orientation Parameters (EOP) combination and prediction solution is produced at approximately 1700 UTC each day; the weekly is produced on Thursday at approximately 1700 UTC. The EOP data include polar motion, UT1, and celestial pole offsets. Observations of past data are combined with appropriate weighting factors and then used, along with some provided forecast data, to predict the EOP solutions into the future. Data from VLBI, Global Positioning System (GPS), SLR, and AAM are used in these EOP solutions, (Wooden et al., 2005). The International VLBI Service (IVS), the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center, and the US Naval Observatory (USNO) periodically provide VLBI data observed over a 24 hour interval; while 1 hour long intensive solutions are also provided by NASA and USNO. The SLR data are provided by the International Laser Ranging Service (ILRS), the Russian Mission Control Center (MCC), and the Institute of Applied Astronomy (of the Russian Academy of Sciences) (IAA). The AAM information comes from two analysis centers: the U. S. Navy Operational Global Atmospheric Prediction System (NOGAPS) and from the National Oceanographic and Atmospheric Administration (NOAA). The GPS solutions, of various kinds, are provided by the IGS; Geodetic Survey Division, Natural Resources Canada (NRCan, formerly EMR Canada); and USNO. The EOP RS/PC combination solution is compared daily to the 05C04 series provided by the EOP Prediction Center (PC) in Paris. The 05C04 series is the 2005 realization of the C04, which is regarded as the EOP reference system. It is estimated there are 1500 users of the IERS RS/PC data. Most uses of the data are for practical, non-research purposes with many users – 85 to 90 % – having limited technical skills.

3. RECENT IMPROVEMENTS IN THE COMBINATION

The IERS RS/PC switched to the system of the 05C04 IERS reference series on June 14, 2007. Electronic transfer of VLBI intensives data (e-VLBI) are decreasing the turnaround time for processing since the data arrive sooner at the RS/PC than they did in the past. The Int1 intensive observations (which use the Wetzell, Germany to Kokee, Hawaii baseline) are typically made Monday through Friday. Starting in August 2005, Wetzell has transferred their data electronically to a location near the USNO, reducing data transfer to about 1 day, allowing Int1 experiments to be reduced with only 2 days of latency. The Int2 intensive, using the Wetzell, Germany to Tsukuba, Japan baseline, also benefited from e-VLBI. The observations collected on Saturday and Sunday are correlated at Tsukuba, Japan via e-VLBI, and the weekend solutions are usually available on Monday.

The ILRS series A and IGS Ultras were added, and two other series were dropped (the Center for Space Research (CSR) and the Delft University of Technology (DUT) SLR) as inputs to the combination software. Note, only IGS Ultra polar motion data which are more recent than the IGS Rapid data are included in the combination. Previously, extrapolated IGS Rapids were used to estimate polar motion beyond the last IGS Rapid point.

As shown in Figure 1, IGS Rapid data are produced daily, and the epoch is at noon UTC the day before the IERS RS/PC daily solution is run. Previously, pseudo-points were created by the RS/PC ±6 hours from noon UTC using the rate and polar motion value at noon. However, starting in July 2007, the IGS Ultra data replaced these extrapolated Rapid values, since the accuracy of the Ultras is better than the pseudo-points. As shown in Figure 3, for close to 4000 days both extrapolated Rapid and Ultra polar motion were compared with the IGS Finals data. The resulting residuals computed using Ultra are significantly lower than the residuals using extrapolated Rapid data. Note, to simplify the analysis, the extrapolated Rapids used to produce Figure 3 were not computed at the 6 and 18 hour epochs, shown in Figure 1; they were computed at epochs to match the Finals data epochs (e.g., at D0 + 12 and D1 + 12). The possibility of using Ultra LOD in the combination procedure is a continuing topic of research.

4. PREDICTION PROCEDURE

The UT1-UTC predictions benefited from faster turnaround times provided by e-VLBI intensives. The least-squares, autoregressive algorithm for polar motion, which was developed by W. Kosek in the 1990s (and later enhanced by T. Johnson) was implemented. AAM data were improved with the addition of the NOGAPS series; this series was combined with the existing NOAA series for a more robust AAM estimation. Also, the NOGAPS and NOAA recently extended the predictions from 5 to 7.5 days potentially increasing the accuracy of the RS/PC UT1 short-term predictions. Lastly, improved AAM diagnostics, in the form of LOD residuals, will be implemented in the future.

5. PREDICTIONS OF POLAR MOTION DATA USING LS-AR

As shown in Figure 2, the polar motion prediction algorithm uses polar motion data from the C04 series, from 1962 to 1973, and the USNO combination data from 1973 to the present. From this data, a median linear fit is created, thus determining a long-term bias and slope. The median fit (as opposed to least squares) is used because of its robust characteristics regarding odd outlier points. It determines the line coefficients which minimize the 1-norm of the error, i.e., finds the minimum of the merit function

$$\Sigma_{i=1}^{N}|y_i - a - bx_i| \tag{1}$$

where, in this case, y_i is the polar motion from the C04 and USNO combination data, a is y-intercept of the line, and b is the slope. The least squares approach would minimize the following merit function,

$$\Sigma_{i=1}^{N}(y_i - a - bx_i)^2. \tag{2}$$

In the least squares case, the odd outlier would have a squared contribution to the merit function of equation (2), as opposed to the non-squared contribution to the merit function in (1). This line is then subtracted from the data, and the resulting residuals are the input to a least-squares (LS) routine to determine significant periodic signals, namely, the Chandler period (433 days), annual (365.2442 days), semiannual, terannual, and $\frac{1}{4}$ annual. These periodic signals are then also subtracted from the residuals, yielding a polar motion minus median fit and periodic signals. The result contains primarily stochastic characteristics, which are fed into an autoregressive forecasting process to generate a predicted signal. The Chandler, annual, and semiannual, bias and slope signals are then added back to the predicted signal, yielding a prediction of the polar motion.

6. IMPROVED PREDICTIONS WITH RECENTLY EXTENDED AAM DATA

The flowchart in Figure 4 illustrates the RS/PC process of obtaining, analyzing, and combining AAM analysis and forecast data from both the NOGAPS and NOAA $\chi_3^{(w)}$ and $\chi_3^{(p)}$ values to estimate the LOD. These χ_3 values are the effective wind and pressure AAM functions related to Earth rotation. First, analysis and forecast files are obtained from Navy and NOAA ftp sites. Preliminary checks on data quality are performed, and for any data files that are missing or corrupt, estimates are created based on the previous day's set of analysis and forecast files. Note that the estimated data files would, of course, be less accurate than the computed versions from the Navy and NOAA. Fifteen days of past analysis and 7.5 days of forecast data are read into each of the RS/PC processing software for the Navy and NOAA data. The 15 analysis and 7.5 forecast days are combined into a continuous series and then filtered twice with a 5 point Hanning window to filter out high frequency noise.

Once the filtered Navy and NOAA χ_3 values are created, if both are determined to be valid and not estimated values, they are simply averaged together to get a combined χ_3 . If any of the Navy or NOAA values are estimated, then that value is de-weighted by 50%. For example if some of the Navy data were estimated over the 15 analysis and 7.5 forecast days, and the NOAA data were not estimated, then the equation for the averaging would be

$$\chi_{3comb} = 0.25 * \chi_{3Navy} + 0.75 * \chi_{3NOAA}. \quad (3)$$

In rare cases when neither estimate nor provided values (from Navy or NOAA) are available, then that missing value will result in a weight of 0.0. For example if no NOAA data were available, then the overall χ_3 value would be computed as follows:

$$\chi_{3comb} = 1.0 * \chi_{3Navy} + 0.0 * \chi_{3NOAA}. \quad (4)$$

If both Navy and NOAA values are estimated, the weighting is slightly toward the NOAA data:

$$\chi_{3comb} = 0.4 * \chi_{3Navy} + 0.6 * \chi_{3NOAA}. \quad (5)$$

The combined χ_3 values are then integrated to form a UT1 estimate, which is used in the combination and prediction software. The AAM data receive a low weight in the combination calculations, but form the basis for UT1 predictions out to 7 days.

7. INTERFACE WITH USERS

The archive notes available through the web pages (http://maia.usno.navy.mil/ser7/archive.notes) have been reinstated. The archive notes are intended to document all changes in data sets and algorithms that are made to the combination and prediction software. These should give a summary of all changes that could potentially impact the quality and reliability of the RS/PC solution. They provide the date and a description of the event so that users of RS/PC data can determine when significant changes were made. The RS/PC has continued to maintain close contact with contributors to and users of the RS/PC solution. On a daily basis, the input data sets are scrutinized and any unusual feature examined to ensure data quality; potential problems are reported to the appropriate contributor in a timely fashion. Communication with RS/PC users is encouraged so that their changing needs are understood. To ensure the reliability of the RS/PC solution, a plan to expand our redundant off-site computer capability is being implemented; it currently includes the acquisition and setup of off-site hardware. There is also a need to rewrite the combination and prediction software to maximize its portability. It is estimated that the hardware and software will be ready for remote operations in the next calendar year.

8. FUTURE DIRECTIONS

In the near future, the EOP RS/PC will be working toward establishing an operational backup at a remote location, establishing increased version control of the combination and prediction software, creating more helpful diagnostics of AAM inputs, and upgrading and enhancing its web pages. Further into the future, using additional AAM data sets in the predictions, IGS Ultra data in the determination of LODs, AAM data in the polar motion predictions, and more extensive e-VLBI use to reduce latency in EOP combinations, are on the agenda.

9. REFERENCES

Wooden, W.H., Johnson, T.J., Kammeyer, P.C., Carter, M.S., Myers, A.E., (2005) "Determination and Prediction of UT1 at the IERS Rapid Service/Prediction Center," Journées Systèmes de Référence Spatio-Temporels 2004, pp 260-264.

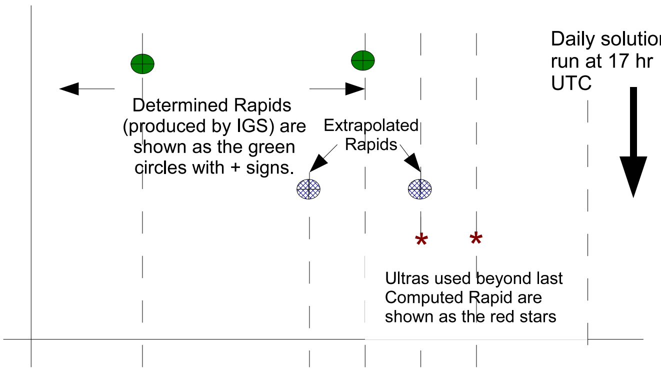

Figure 1: Replacement of Extrapolated Rapid with IGS Ultra Data

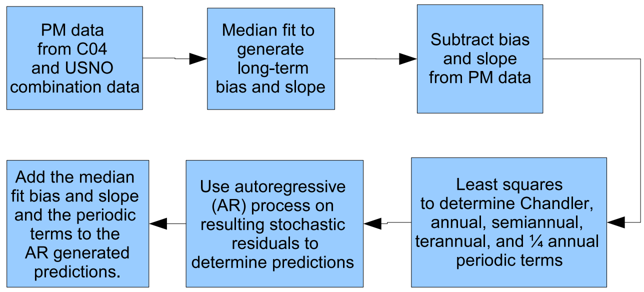

Figure 2: Polar Motion Least Squares / Auto Regression (LS/AR) Polar Motion Prediction Algorithm

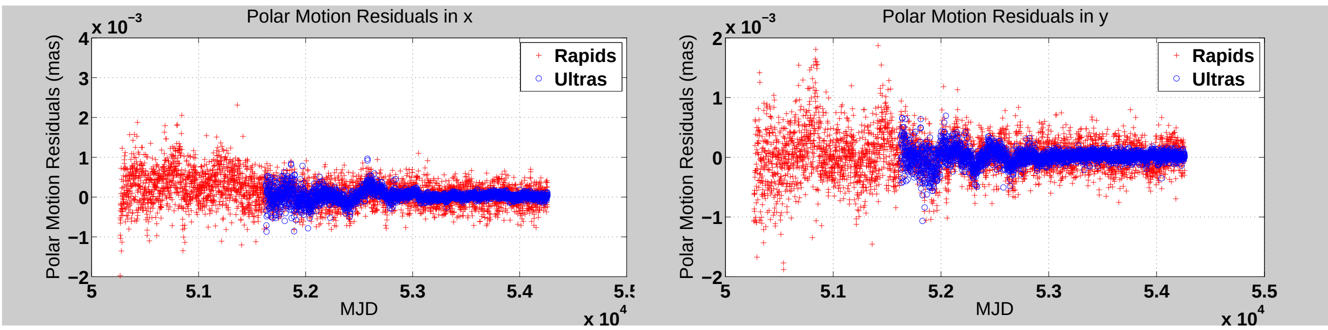

Figure 3: Polar Motion X and Y Residuals – Extrapolated IGS Rapid vs. Ultra data

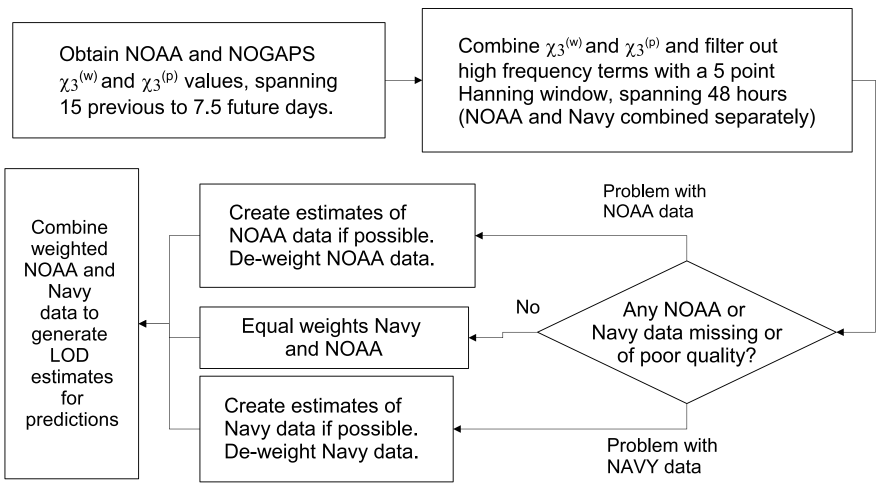

Figure 4: LOD Estimation Details